

THE MANGANESE MERCURY STAR π_1 BOOTIS

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Abstract.—High-dispersion plates secured with the Coudé spectrograph of the Lick 120 inch telescope have been used to analyze the peculiar A star π_1 Bootis. Spectral-energy distribution measurements are combined with line-intensity data for iron and manganese in two stages of ionization to obtain a fit with model atmospheres for $T_{\text{eff}} = 13,000^{\circ}\text{K}$ and $\log g = 4$. The influence of adopted T and g on the derived abundances is discussed. Although C, O, Mg, Si, Ti, Cr, and Fe appear to have nearly normal (i.e., solar) abundances, strontium appears to be enhanced in abundance by an order of magnitude, and scandium is about 50 times overabundant, while manganese and yttrium appear to be two orders of magnitude overabundant. If the identification of gallium is correct, this element is overabundant by a factor approaching 100,000; while if $\lambda 3983.90$ is to be attributed to HgII, as Bidelman suggests, the overabundance of this element is many orders of magnitude.

The manganese star¹ π_1 Bootis, HD129174, spectral class B9IIIp² shows magnetic field variations from -75 to $+190$ gauss³ and possible spectrum variations with a period of $2^d 2445.4$. There is some evidence for a slight velocity variation from -0.8 to -2.5 km/sec. Abundance determinations have been made by several groups.⁵⁻⁶

With the Coudé spectrograph of the 120-inch Lick reflector we secured observations in the $\lambda 3400$ – 4650 region with a dispersion of 2.2A/mm as follows: plate no. 1784 Feb. 7.55, 1963; no. 2691 Feb. 21.40, 1964; and no. 2695 Feb. 22.35, 1964 (universal time). Visual region plates no. 2621 Jan. 1.05, 1964, and no. 3178 July 26.17, 1964, covered the region $\lambda 5150$ – 6600 . Our line identifications agree well with those of Jaschek, *et al.*,⁷ although there are some differences for fainter lines. All plates were microphotometered at UCLA. Equivalent widths from different plates in the blue were in good agreement, but the lower-dispersion visual plates showed larger errors. A medium strength line there might have a 30 per cent error.

An energy distribution (Table 1), measured in 1965 with Oke's photoelectric spectrum scanner attached to the Mt. Wilson 60-inch reflector, yielded a Balmer jump of 0.8 magnitudes but a rather poor fit with the energy distribution pre-

TABLE 1. *Measured energy distribution.*⁽¹¹⁾*

$M(1/\lambda) = -2.5 \log F(1/\lambda)$							
λ	$M(1/\lambda)$	λ	$M(1/\lambda)$	λ	$M(1/\lambda)$	λ	$M(1/\lambda)$
5840	+0.21	4785	-0.10	4167	-0.20	3571	+0.56
5556	+0.09	4566	-0.10	4032	-0.23	3509	+0.59
5263	+0.07	4463	-0.14	3704	+0.55	3448	+0.58
5000	0.00	4257	-0.17	3636	+0.58	3390	+0.58

* Standard star was Vega, whose energy distribution was measured by D. Hayes, thesis UCLA (1967).

TABLE 2. *The hydrogen line profile H γ .*⁽¹⁾

$\Delta \lambda (\text{\AA})$	1.5	2	3	4	5	6
Residual intensity	48	51.5	59	65	70.5	75
$\Delta \lambda (\text{\AA})$	8	10	12	15	18	22
Residual intensity	82.5	87	90	93.5	95.5	97

dicted by the Strom-Avrett⁸ models. Space reddening is negligible. Improved energy-distribution data covering a longer wavelength range and theoretical models including effects of line blanketing and departures from local thermodynamic equilibrium are evidently needed. If $\log g$ lies between 3 and 4, the Balmer discontinuity implies a temperature of 13,000°K.

Our observed $H\gamma$ profile (Table 2), interpreted with Mihalas⁹ theoretical $H\gamma$ profiles, gave best fits for $\log g = 3$ ($T_E = 11,200^\circ\text{K}$) or $\log g = 3.5$ ($T = 12,600^\circ\text{K}$). More recent theoretical work on $H\gamma$ -line broadening suggests these $\log g$'s might be increased by about 0.2–0.3.

TABLE 3. *Lines used in abundance analysis.*

(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
CII			4374.46	21	4.91B	4051.97	18	6.49G
3918.98	19	4.95T	4400.36	22	5.18B	4082.30	11/4	5.77W
3920.68	34	4.65T	4415.56	17	5.29B	4132.41	16	6.29W
4267.02	31	3.90T				4145.77	25/2	5.23W
4267.25	32	3.72T	3504.89*	25	3.20W	4224.85	25	5.39W
OI			3741.63	35	4.09W	4269.28	20	5.97W
6155.98	21	5.00K	3757.68	17/4	4.46W	4275.57	32	6.18W
6156.77	31	4.71K	3759.29	73/1	4.18B	4555.02	37	5.45W
6158.18	46	4.56K	3900.55	43/9	4.54W	4558.66*	69	5.53W
MgII			3913.46	40	4.65W	4565.78	17	4.40W
4384.64	24	5.17G	4028.33	22/2	5.04W	4592.09	30	6.00W
4390.58	44	4.92K	4163.64	18	4.18W			5.46W
4481.13	269	3.77K	4290.22	26	5.16W	MnI		
			4301.93	15	5.48W	3547.80	11	3.41B
SiII			4312.86	14/2	5.42W	3569.49	22	3.17B
3853.66	69/1	6.10G	4395.03	31	4.86W	3790.22	6/10	4.52B
3856.02	118	5.15G	4399.77	11	5.42W	3799.26	2/51	5.20B
3862.59	98	5.38G	4443.80	27	5.09W	3806.72*	23/8	3.45B
4075.45	22/2	6.01T	4468.49	33	5.00W	3809.59*	4/3	4.08B
4076.78*	15/2	6.28T	4501.27	23	5.14W	3823.51*	18/3	3.61B
4130.88	137	3.98G	4563.76	17	5.20W	4018.10	13	4.04B
CaII			4571.97	29	4.68W	4030.76	34	4.88B
3706.03	49/4	4.65B	4589.96*	23	5.95B	4034.49	19	5.27B
3736.90	45/26	4.54B	CrII			4035.73	10	4.02B
3933.66	219	4.23K	3408.76	76	4.15B	4041.36	33	3.46B
3968.47	90/56	5.37B	3421.20*	53	4.51W	4055.54*	10	3.92B
ScII			3422.74*	64	4.30B	4058.93	11	4.13B
3558.54	28	4.70B	3433.30*	49	4.46A	4063.53	12	4.31B
3567.70	25	4.93B	3475.13	22	5.75W	4079.24	11/3	4.33B
3572.52	47	4.40B	3484.15	21	5.88W	MnII		
3576.34*	50	4.54B	3495.37	35	5.43W	3428.15*	49	5.70W
3580.93	38	4.66B	3511.84	29	5.40W	3438.98	91	6.21W
3589.64	19	4.93B	3585.31	65	4.45W	3441.98	192	4.41B
3590.48	16	4.92B	3613.21	26	5.54W	3446.00	25	6.34W
3613.84	48	4.09B	3651.68	27	6.52W	3449.50	29	6.07W
3630.74	36	4.26B	3738.38*	25/14	5.32W	3457.81	41	5.82W
3642.78	34	4.45B	3754.59*	30/22	5.61W	3460.04	65	5.93W
3645.31	22	4.73B	3814.00	34	5.38W	3460.31	133	4.69B
4246.83*	55	4.28B	3865.59	37	4.82W	3462.34	21	6.40W
4305.72	20	5.66B	3979.51	27	4.84W	3472.21*	37	6.48W
4314.08*	37/3	4.56B	4003.33	21	4.93W	3482.06	42	5.35W
4320.74*	28/4	4.68B	4038.03	17	4.75W	3482.90	105	4.78B

TABLE 3. (continued)

(1)	(2)	(3)	(1)	(2)	(3)	(1)	(2)	(3)
3485.40	16	6.81W	3975.74	17/26	5.61W	4508.28	36	6.11W
3488.68	115	4.97B	3994.12	17/1	5.46W	4515.34	31	6.25W
3489.30	20	6.17W	3995.31	22/1	7.06W	4520.22	25	6.21W
3492.28*	40	5.68W	4000.04	42/1	5.40W	4522.63	39	5.85W
3495.83	111	5.11W	4081.46	42/4	5.87W	4541.52	12	6.63W
3496.81	60	5.50W	4105.00	36/40	5.36W	4555.89	30	6.13W
3497.54	84	5.18W	4174.31	53	7.70W	4576.33	19	6.56W
3508.32	23	6.02W	4184.47	40	6.05W	4582.84	9	6.78W
3614.44	14	5.69W	4200.28	47	5.50W	4583.83*	47	5.59W
3627.48	32	4.75W	4205.40	65	7.64W			
3656.49	22	5.14W	4206.38	112	5.50W	SrII		
3662.13	9	6.30W	4239.19	54	6.20W	4077.71	66/3	5.17B
3668.01	18	5.74W	4244.26	49	5.99W	4215.52	60	5.36B
3683.62	29	5.57W	4251.74	63	5.13W	GaII		
3686.79	21/5	6.70W	4281.94	59	6.29W	4251.18	49	3.91D
3690.32	21/4	5.97W	4283.77	58	6.09W	4255.75	91	3.69D
3695.92	35/5	5.79W	4292.25	94	5.76W			
3701.39	28/2	5.98W	4326.76	102/8	5.26W	YII		
3706.89	32	6.08W	4342.58	30/50	6.05W	3584.53	32	4.99Z
3708.06	47	5.70W	4343.98	87/38	5.12W	3600.74	58	4.05Z
3709.86	25/13	5.64W	4365.22	43/3	5.53W	3601.93*	51	4.55Z
3713.63	13/17	6.20W	4434.06	55	5.70W	3611.06	46	4.36Z
3714.78	13/7	5.39W	4478.64	56	5.27W	3633.13	42	4.58Z
3717.10	28	6.50W				3664.62	46	4.67Z
3717.52	34/1	6.15W	FeI			3710.30*	37/17	3.84Z
3724.81	24/14	6.13W	3758.24	8/4	4.06C	3774.33*	58/31	4.06Z
3727.24	22	6.14W	3799.55*	6/49	4.85C	3776.56	38/16	4.71Z
3729.49	46/4	5.71W	3815.84	4	3.82C	3782.30	27	3.89Z
3740.30	33/97	5.63W	3820.43	5/4	4.01C	3788.70	59/6	4.32Z
3755.20	30/17	5.40W	3825.88	7/8	4.18C	3818.34	43	5.13Z
3764.85	25/12	6.53W	3827.80	5/14	3.89C	3832.89	25/46	4.98Z
3767.51	20/32	5.89W				3878.28*	27/10	6.51Z
3817.26	22	5.73W	FeII			3930.66*	26	5.98Z
3825.04	45/6	6.33W	3468.68*	20	5.39W	3950.35	52/2	4.84Z
3839.05	25/35	6.18W	3493.47	25	5.11W	3951.59*	12/3	4.37Z
3843.33	10/15	6.46W	3762.89	13/4	5.57W	3982.59	56/8	4.88Z
3848.57	23/4	6.76W	3783.35	9	7.07W	4204.70	21	6.10Z
3859.21	17	6.21W	3935.94	14	5.36G	4235.73	32	4.98Z
3863.40	32	6.61W	3938.97*	13	5.79W	4309.62	45/1	4.24Z
3879.00	52/11	5.90W	4173.45	33	6.39W	4358.73	27/5	4.89Z
3897.62	53/15	6.18W	4178.86	27	6.38W	4374.94	65	4.63Z
3898.07	44/14	5.81W	4296.57	21	6.73W	4398.02	45	4.50Z
3917.32	39	5.51W	4351.76*	19/12	6.12W	4422.59	39	4.78Z
3930.97	28	5.84W	4416.82	29	6.44W			
3941.22	35	6.31W	4489.18	19	6.58W	HgII		
3952.42	28/4	5.79W	4491.40	26	6.44W	3983.90	136/6	4.40A

Column (1) wavelength λ ; (2) equivalent width W, in millangstroms, and when it exists, depression of continuum in per cent, e.g., 45/26 means $W = 45\text{mA}$ and line falls in the wing of a broad line so its "local continuum" falls 26% below background continuum. (3) gives $[-\log(gf\lambda)]$ where g is the statistical weight of the lower level, and the source of the oscillator strength (f-value) is coded according to the following scheme; (A) Assumed $gf = 1$; (B) Corliss, C. H., and W. R. Bozman, *Natl. Bur. Std. U.S., Monograph*, 53 (1962); (C) Corliss, C. H., and B. Warner, *Astrophys. J. Suppl.*, 8, 395 (1964); (D) coulomb approximation; see Bates, D. R., and A. Damgaard, *Phil. Trans. Roy. Soc., A*, 242, 101 (1949); (G) Groth, H. G., *Z. Astrophys.*, 51, 231 (1961); (K) Kohl, K., *Z. Astrophys.*, 64, 115 (1964); (T), Auer, L. H., et al., *Astrophys. J.*, 145, 153 (1966); (W) Warner, B., *Mem. Royal Astron. Soc.*, 70, 165 (1967); (Z) Krueger, T. K., L. H. Aller, J. Ross, and S. J. Czyzak, *Astro-phys. J.*, 152, 765 (1968).

* Indicates that the line was rejected in the final analysis by the computer program.

Our next task is to interpret the measured line intensities with the art of theoretical line intensities computed for the Strom-Avrett models. In practice we choose combinations of models $T = 12,000, 13,000$, and $14,000^\circ\text{K}$ with $\log g$ of 3 or 4, and derive abundances by a comparison of observed and predicted

TABLE 4. Additional lines in the spectrum of π_1 Bootis.

λ	I	W	λ	I	W	λ	I	W
3419.50	—	60	4120.80	HeI	59/2	4503.20	MnII	27
3420.00	—	37	4123.50	—	19	4518.96	MnII*	57
3451.32	FeII	35	4124.79	FeY	27	4525.32	MnII*	56
3461.46	MnII	25	4128.05	SiMn	142	4533.97	FeTi	32
3474.28	MnII	190	4128.74	FeMn	17	4549.47	FeTi	84
3494.16	MnII	10:	4136.95	MnII	101	4588.22	CrII	64:
3494.38	MnII	17:	4140.44	MnII	31	4596.09	FeIII?	8
3509.94	MnII*	64	4143.76	HeI	130:	4602.08	PII??	13
3510.84	TiMn	36	4162.50	—	52?/15	4616.54	CrII	33:
3532.00	MnI*	16	4171.04	MnII	35	4618.83	CrII	55:
3563.12	MnII	38	4171.6	MnFe	34:	4629.34	FeII	27:
3570.04	MnI	21	4171.9	Blnd	60	4634.11	CrII	47:
3570.60	—	14	4177.47	MnY	94	5169.02	FeII	70:
3578.20	—	22	4178.40	—	12	5177.64	MnII	57:
3583.04	MnI	19	4179.40	CrII?	21	5196.42	YII	29:
3591.38	MnII	5	4180.03	MnII	16	5200.41	YII	40:
3603.70	CrII*	30:	4189.56	FeI?	11	5205.72	YII	59:
3628.65	MnY	28	4207.23	MnII	17	5234.61	FeII	27:
3631.45	MnCr	50:	4218.50	—	19	5237.33	CrII	65:
3632.46	MnII	7	4233.17	{ FeII	67:	5239.81	ScII	36:
3677.86	CrII*	74	4233.25	{ CrII	48:	5251.81	MnII	34:
3682.20	—	18/2	4237.87	MnII	28	5274.98	CrII	27:
3685.10	TiMn	118:	4238.79	MnII	53	5275.98	FeII	33
3686.15	MnII*	22/4	4242.35	MnCr	83	5289.81	YII	18
3694.11	CaII*	53	4242.92	MnII	34	5294.21	MnII	78
3713.00	CrII*	25/23	4247.95	MnII	57	5295.28	MnII	100
3715.27	MnCr	76/4	4253.02	MnII	140	5296.96	MnII	119
3725.28	MnFe	25/10	4254.13	GaII	28	5299.27	MnII	138
3727.04	FeII	15/1	4261.92	CrGa	92	5302.31	MnII	104
3728.72	MnII	22/1	4263.20	—	20	5308.43	CrII	33
3730.07	MnII	44/7	4267.85	MnII	23	5313.58	CrII	25
3736.90	CaII	45/26	4275.87	MnII	13	5316.60	FeII*	80
3743.39	MnFe	81/2	4282.26	MnII*	93	5402.77	YII	47
3747.55	YCr	22/32	4284.21	{ CrMn	66:	5421.91	MnII	34
3761.32	TiIII	66	4284.42	{ MnCr	58:	5473.39	YII	25
3761.90	CrII*	28/1	4288.07	MnII	34	5480.74	YII	27
3763.74	MnFe	112/6	4289.60	MnII	20	5497.41	YII	44
3778.32	MnFe	59/9	4291.96	MnII	13	5501.11	MnII	29:
3783.91	MnII	23	4294.10	TiFe	34	5509.96	MnY	83:
3812.21	MnII*	103	4300.05	TiMn	84	5511.47	MnII	34
3819.61	HeI	94/1	4302.96	FeMn	65	5521.55	YII	25
3844.17	Mn?	97/12	4307.90	{ TIII	10:	5544.60	YII	23:
3848.19	YII	24	4308.16	{ MnII	52:	5546.01	YII	24
3867.48	HeI	45	4310.70	MnII?	24/1	5559.04	MnII	63
3902.38	MnII	19/6	4314.37	MnII	12/3	5570.60	MnII	86
3903.90	FeI?	9/5	4318.52	MnII	21/3	5578.14	MnII	64
3905.46	MnII*	67/4	4325.01	MnSc	59/7	5662.94	Y Fe	55
3926.47	Mn*	50	4331.68	MnII	11/18	5826.28	MnII	35
3943.60	MnII	50:	4345.58	MnII	29/29	5875.64	HeI	97
3943.86	MnII	81:	4346.39	MnII	28/25	5957.60	SiII	79:
3986.61	MnII?	33/5	4348.39	MnII	67/18	5978.96	SiII*	115:
3996.38	MnII?	19	4356.63	MnII	46/7	6105.37	MnII	51
4009.27	HeI	65	4363.26	MnII	45/3	6122.79	Mn*	109
4012.47	FeCr	30	4377.74	MnII	30	6126.20	Mn*	124
4026.19	HeI	328	4379.63	MnII	43	6129.01	Mn*	119
4032.95	MnFe	57	4385.38	FeMn	31	6130.99	Mn*	85
4039.8	—	20	4387.90	HeI	112	6131.91	MnII	36
4070.28	MnI	14/2	4391.96	MnII	12	6334.60	—	77
4070.6	—	12/2	4393.38	MnII	29	6347.08	SiII	185:
4083.63	Mn*	25/5	4403.50	MnII	24	6370.37	...	45
4085.39	MnII	40/6	4441.99	MnII	24	6371.35	SiII	145:
4087.90	MnII	13/8	4451.55	FeII	19	6419.14	—	78
4094.41	MnII	10/20	4471.48	HeI	206:	6446.28	Mn*	22
4110.62	MnII	45/16	4497.95	MnII	21	6455.99	—	59:
4111.02	CrII	20/15	4500.55	MnII	33	6457.25	MnII	76

Column (1) gives adopted wavelengths, (2) identification, (*) denotes a blend with another line of same element. For other blends, elements are listed, although detail on stage of ionization is not included. (3) gives equivalent width and lowering of continuum expressed in per cent when relevant.

intensities. For the correct (T, g) combination one should obtain the same abundance from two different ionization stages, e.g., MnI, MnII, FeI, and FeII. The result also depends on the assumed value of the turbulent velocity ξ . For $\xi = 0$, abundances derived from lines longward of the Balmer jump were systematically lower than from those shortward of the Balmer jump. Trials with $\xi = 0, 2, 4$, and 6 km/sec suggested that $\xi = 4 \text{ km/sec}$ is the best choice. Final abundances are tabulated for a model $T = 13,000$, $\log g = 4$. Ionization balance was obtained for (MnI, MnII) and (FeI, FeII).

As ξ is increased, abundances (A) remain relatively constant, but the temperature and gravity demanded by the ionization balance increase somewhat. For each element we tabulate not only $\log A$ but also coefficients in the expression $\log A(T, g) = \log A(T_o, g_o) + \alpha(T - T_o) + \beta \log(g/g_o)$, where $T_o = 13,000 \text{ K}$, $\log g_o = 4$. These coefficients, computed by least squares, are based on pivotal points ($T/10,000, \log g$) as follows: (1.2; 3), (1.2; 4), (1.3; 3), (1.3; 4), (1.4; 3), (1.4; 4).

Table 3 lists the lines used in the abundance analysis. Table 4 gives additional lines that were not used because of blends, poor quality, inadequacies in the atomic data, or in theory of line broadening, while Table 5 gives the final results. Comparing with solar abundances¹⁰ Ca appears under abundant, Sc, Mn, Sr, Ga, and Y are overabundant; Hg is strongly overabundant if the assumed f value is reasonably correct. All other elements appear to have normal abundances.

TABLE 5. Abundances in π_1 Bootis ($\log N(H) = 12.00$).

El.	No.	$\log N$	α	β	El.	No.	$\log N$	α	β		
C	4	8.86 ± 0.08	CII	-0.140	+0.537	Mn	12	6.94 ± 0.17	MnI	+0.416	-0.437
O	3	8.73 ± 0.04	OI	+0.075	-0.020	MnII	78	6.88 ± 0.41	MnII	+0.138	+0.077
Mg	3	7.49 ± 0.37	MgII	+0.080	+0.027	Fe	5	6.32 ± 0.15	FeI	+0.438	-0.367
Si	5	7.26 ± 0.28	SiII	+0.028	+0.207	FeII	18	6.31 ± 0.14	FeII	+0.163	+0.177
Ca	4	5.09 ± 0.20	CaII	+0.313	-0.087	Ga	2	7.23 ± 0.23	GaII	-0.130	+0.290
Sc	14	4.72 ± 0.19	ScII	+0.355	-0.060	Sr	2	4.81 ± 0.07	SrII	+0.350	-0.093
Ti	17	4.69 ± 0.27	TII	+0.305	-0.037	Y	19	4.82 ± 0.44	YII	+0.345	-0.140
Cr	24	5.84 ± 0.14	CrII	+0.190	+0.097	Hg	1	4.26::	HgII

Successive columns give the element, the number of lines employed, $\log N$ with mean error calculated from internal agreement of data, and the coefficients, $\alpha \times 10^{-3}$ and β . Helium abundance is being discussed separately. Carbon abundance is derived from multiplets 4 and 6. Oxygen abundance is derived entirely from multiplet 10 for which observational data appear to be satisfactory. Magnesium abundance is derived from multiplets 4 and 10; λ4481 is a close-blended doublet and should be treated by direct numerical integrations. Titanium and chromium gave poor fits to curve of growth, indicating a lower value for turbulence. Manganese and iron were used to establish the ionization equilibrium. Ionized gallium, identified by Bidelman, is represented by four lines, for two of which C. Seligman has calculated f -values by the Bates-Damgaard method. Gallium appears to be overabundant by several orders of magnitude. Strontium abundance is reduced by a factor of 10 if one uses $f' = 1.2$ (λ4077) (Allen, C. W., in *Astrophysical Quantities* (London: Athlone Press, 1963), 2nd ed., p. 73) rather than Corliss-Bozman data. Yttrium data show a large scatter. Mercury appears to be represented by Hg λ3983.9A, whose high intensity implies a great excess of this element.

Since this investigation was completed and while it was being prepared for publication, we received a preprint of a manganese star study by Mrs. K. Strom. She has utilized Mt. Wilson data for π_1 Bootis of somewhat lower dispersion than we have employed. Her analysis suggests a lower effective temperature and different $\log g$ but reaches qualitatively similar conclusions concerning the excess of manganese, scandium, strontium, gallium, and mercury. The quantitative results differ, however.

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¹ Morgan, W. W., *Astrophys. J.*, **73**, 104 (1931); Bertaud, Ch. *Journal des Observateurs*, **42**, 45 (1958).

² Osawa, K., *Astrophys. J.*, **130**, 159 (1959).

³ Babcock, H. W., *Astrophys. J. Suppl. Ser.*, **3**, 141 (1958); *Astrophys. J.*, **128**, 228 (1958).

⁴ Deutsch, A. J., *Astrophys. J.*, **105**, 283 (1947).

⁵ Searle, L., W. T. Lundershausen, and W. L. W. Sargent, *Astrophys. J.*, **145**, 141 (1966).

⁶ Mihalas, D., and J. L. Henshaw, *Astrophys. J.*, **144**, 25 (1966).

⁷ Jaschek, M., C. Jaschek, and Z. González, *Z. Astrophys.*, **62**, 21 (1965).

⁸ Strom, S., and E. Avrett, *Astrophys. J. Suppl.*, **12**, 1 (1965).

⁹ Mihalas, D., *Astrophys. J. Suppl.*, **9**, 321 (1965).

¹⁰ See e.g. compilation by Aller, L. H., *Proc. Astron. Soc. of Australia*, **1**, 133 (1968).

¹¹ See also, Aller, L. H. *Proc. Astron. Soc. Australia*, **2** (1969) in press.